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Further Studies of a Ground Penetrating Radar for the Detection of Buried Mines

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16. Abstract (Limit: 200 words)

Research accomplishments on Video Pulse Mine Detection concepts are reported. The program has been extremely successful in meeting and extending our original goals. At this time, it is suggested that if this program were continued, a successful operational mine detector would be the end result.

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TRANSIENT RADAR
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OFF SET REFLECTOR
COMPLEX NATURAL RESONANCE
TARGET IDENTIFICATION

b. Identifiers/Open-Ended Terms

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I. Introduction

The ElectroScience Laboratory has developed a Video Pulse Radar Mine Detection System under previous support from Fort Belvoir. This system included a target identification procedure based on a transient type of return It made use of a crossed loaded dipole configuration to isolate the transmitted and received signal. This system has been modified and used by the British for clearing mines in the Faulkland Islands. The British examined all potential mine detection systems and came to the conclusion that our approach was the best available according to Dr. Allen Rudge. They originally proposed a series of modifications including the use of a stepped frequency approach based on an HP 8510. Richard Chignall has since informed us that their studies showed our video pulse approach was much superior and they accordingly used our basic concepts. They also used an antenna composed of a tapered resistive material. Today there are even more improved commercially-available material in the United States from Brunswick. Thus, an improved antenna design is still practical! Chignall has also stated that their system detected and identified every mine. However, we were also informed that the detection was extremely slow and very expensive when large areas were to be explored.

We observe that Fort Belvoir felt it is not appropriate for Army needs because it must be in close contact with the ground. A study was initiated to explore options for eliminating this problem.

This effort was to be a two year study. However, after only 9 months, the ElectroScience Laboratory was informed that the second year would not be funded for financial reasons.

Since we had made substantial progress, we believe that the proposed second year of research should be completed and that our goals would be achieved. We also believe that this would be a very important contribution as we shall outline in the following paragraphs. First, we have been informed that the casualties in Vietnam caused by mines exceeded all other sources of casualties and that there remain no realistic means of detecting these mines. Consequently, it is essential that some such technique be developed. This is particularly true since the likelihood of global wars has decreased in the past few years and so most U.S. armed forces' actions will take the form of local engagements where mines represent a very significant factor.

The reason for the expense of operation of the previous system was in line with Fort Belvoir's objection to close contact with the earth. The reasons for the close contact was that the incident and reflected fields would set up a frequency dependent standing wave pattern and thus, it would be impossible to couple a very broad band signal to the mine from a single antenna. Our proposed solution was to use time gating techniques to eliminate the incident wave from the received signal. It was also essential to locate the mine accurately. Any antenna placed far enough away from the surface to allow gating to be effective would experience significant beam spreading. Here our response was to introduce focussing at the ground.

We proposed a defocussed parabolic reflector with a secondary focus at the ground. As the study progressed during the first nine months, we also suggested a "time domain" array with a scanning focussed spot would also present very significant advantages.

The following sections will describe the system originally proposed to Fort Belvoir, the research done both in terms of the system and also in terms of the target identification techniques. It is suggested that an additional two year follow-up effort would be extremely profitable. It would be pursued in the first year on demonstrating use of the existing reflector concept for mine detection. The second year would pursue array concepts that would outline the potential in terms of reduced time to explore a given region for such mines. Results generated by both the reflector and the array would be used to expand and test the target identification schemes.

The target identification schemes used in the earlier work [1]-[2] require that the target resonances be found, usually via a Prony procedure. In simplistic terms, these are used to find the coefficients of a Difference (predictor) Equation. Then this Predictor Equation is used to find a future point(s) on the measured scattered field waveform. If these predicted points correlate with measured points then the target is identified with the one associated with the target from which these coefficients have been obtained. This would be contained in a black box as far as the user is concerned. This approach is essential if a fast mine detector is to be evolved. There simply must be a rapid means requiring no user interaction to identify a target such as a mine since there are numerous false scatterers in any practical situation. One can easily envision the disaster that is waiting to happen if an advancing military convoy is sitting on a road waiting for mines to be removed. Substantial progress has also been made in more accurately computing these natural resonances.

The processing to be described in the following program made use of experimental data generated either in the ESL compact range for free space plane wave excitation or for buried targets using a cross dipole configuration.

II. Simplified Description of New Mine Detector Antenna System

Figure 1 illustrated the concept as originally proposed. This involved defocussing the feed antenna element so that a secondary focus exists at the ground. Ideally this would use an elliptical instead of a parabolic reflector but construction costs prohibit this simple solution. In any event, the design of the feed system is crucial since approximately a 10:1 bandwidth is required. The crossed dipole system avoided this problem since the target was located within the fringe fields of the antenna.

An adequate reflector was acquired from Anderson at extremely low cost. A sketch of this antenna is shown in Figure 2. The feed developed at OSU is the simple balun commonly used in most broad band antennas as illustrated in Figures 3a and 3b.

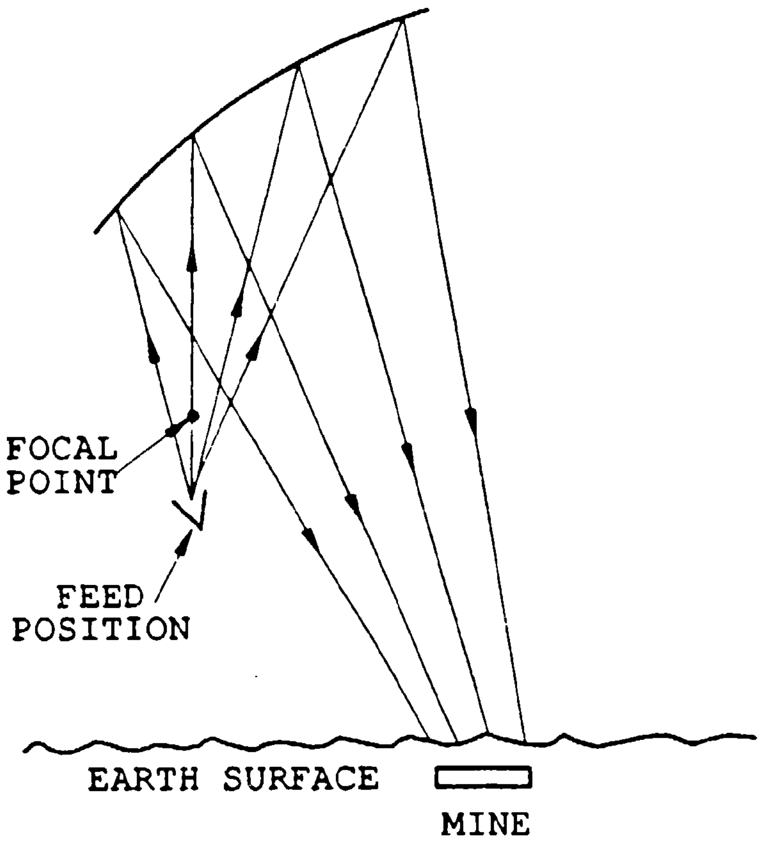


Figure 1: Use of reflector to focus fields on mine (defocussed parabola).

III. Experimental Field Probe Data

The antenna of Figure 2 was excited by a 350 ps wide base band pulse. The received system was a sampling oscilloscope. Several probe antennas were used including a long balun feed coaxial antenna as shown in Figures 3a and 3b, a 500 MHz AEL horn and a 1-18 GHz AEL horn.

These measurements have been completed. An example is shown in Figure 4 where the probe antenna is the long balun fed antenna. The receive pulse is shown in Figure 4 where the time domain is measured at the second focus, i. e. desired focal point, and at successive 2 inch distances from that focus. Clearly the fields decay rapidly as the balun moves away from the focus. The frequency response is also shown. Note that it has been corrected to remove cable losses. However, no other calibration has been introduced.

A 300 MHz filter was used to eliminate local TV noise, since there are a number of nearby stations. The patterns at any single frequency agree reasonably well with computed patterns.

Using one arm of the cross dipole [2], the polarization properties were also measured. The cross polarized components are in general at the minus 20 dB level.

It was planned to obtain a more adequate calibration. This was not completed but it is suggested that the low frequency "droop" is caused by the filter and the high frequency droop by the measurement probe. Even so, this is a remarkable result in that the system response at the second

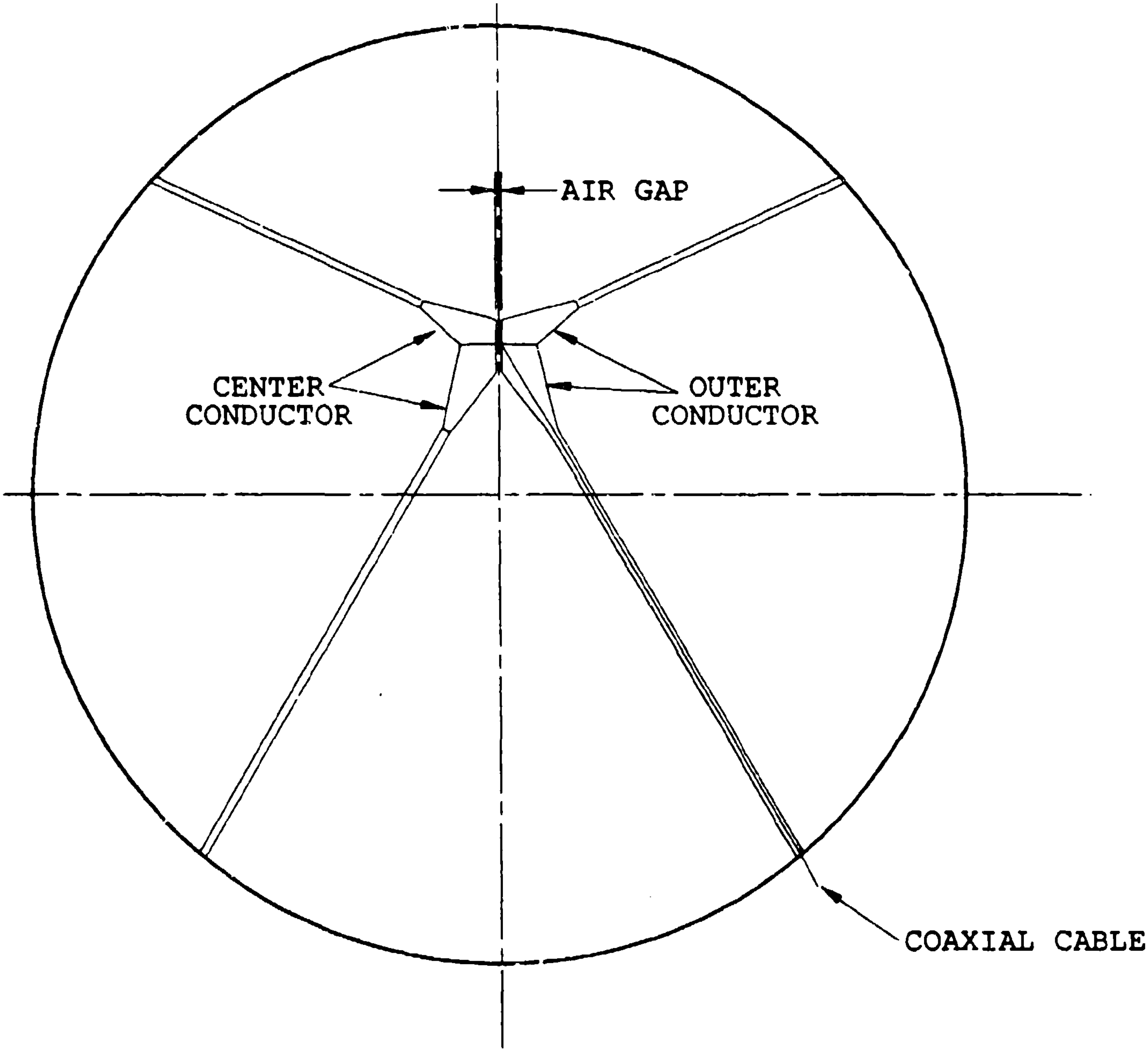
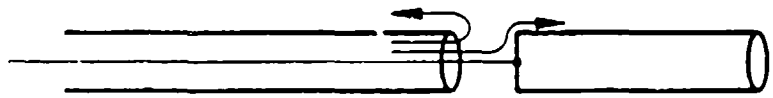


Figure 2:



Figu·e 3a: Illustration of balun feed.

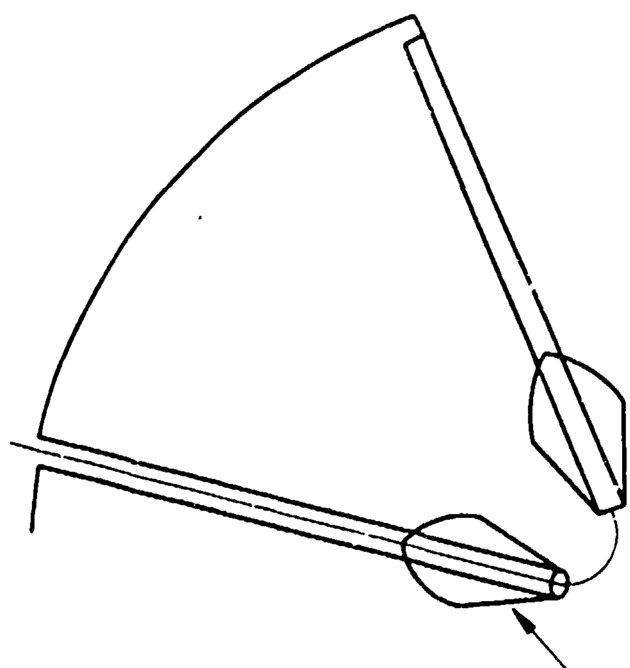
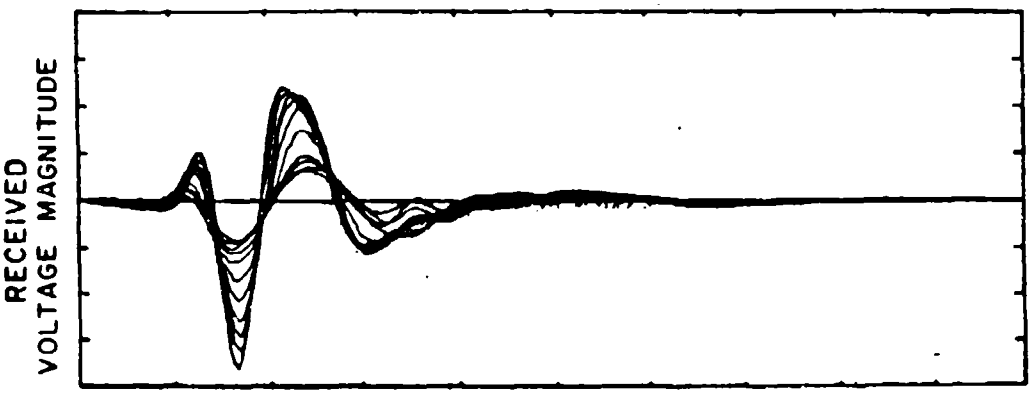
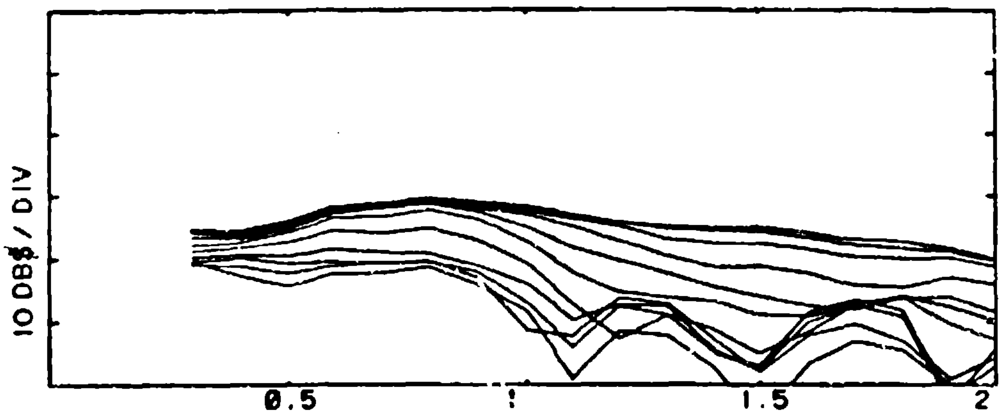


Figure 3b: Illustration of balun feed as implemented in the reflector.



a) Time in Nanoseconds



b) Frequency in GHz

Figure 4: a) Received time domain signal as balun is moved in 2″ increments from the focus, b) frequency response

focus is almost flat over a 10:1 frequency band. Thus a successful antenna with the appropriate broad band feed has been designed, constructed and tested. Its performance has exceeded our expectations.

These measurements were just being completed when the research was terminated. The next step would be to acquire scattering data from the simulated mines to be used to extract the natural resonances and to develop the appropriate identification algorithms.

IV. Data Accumulation

Early in the terminated study, the response of a set of simulated mines furnished by the sponsor were measured under two conditions. First, these simulated mines were studied using plane wave illumination from 2 to 18 GHz in the ESL compact range facility. The radar system can be scanned from 2 to 18 GHz in a few seconds and this data can be accurately calibrated. The purpose of these measurements was to examine the mines for higher frequency resonances and to use them to refine the concepts used for extraction of the targets natural resonances. Low frequency data was generated using the base band pulse system in conjunction with the earlier cross dipole.

What could be considered an initial phase process of the simulated mine-like targets, both in free space and on and within a sandy soil medium, was completed. This processing includes a comparison of the complex natural resonances (CNR) extracted using our own somewhat dated programs with those CNR obtained using a more recent program supplied by Professor Don Dudley of the University of Arizona. In general, an order of magnitude improvement over our older procedures can be seen, both in the pole extraction process and in the clustering of these pole locations, as various target orientations and radar polarizations are tested. The superiority of the externally supplied program is clearly evident. The original version of this program was written by Dennis Goodman of Lawrence Livermore Laboratory but efforts to secure the original source deck, or a copy, have not yet been successful. We are still hopeful of securing a source deck for this program. A graduate student at OSU has recently developed another program that appears to give even better results. The measured targets consisted of three inert mine detection targets furnished by Fort Belvoir. The targets have essentially the same electromagnetic characteristics as "typical" land mines. These targets, nonmetallic, are known as "EM" targets. They are basically plastic discs with different filler materials with the overall dimensions given below.

target	diameter(inches)	thickness(inches)
1	12	3
2	6	2
3	3	1

The primary feature of the mine is the filler material. Size 1 targets (12″ Dia) utilize a mixture of 75% Nylon resin and 25% Carnauba wax. This results in a dielectric constant and (loss tangent) of 2.72 (0.0104) at 100 MHz, 2.70 (0.0069) at 300 MHz, 2.70 (0.0043) at 600 MHz, 2.72 (0.0042) at 900 GHz, and 2.74 (0.0051) at 1000 MHz. This compares to 2.89 (0.0039) at 300 MHz for TNT as reported by Von Hippel.

Size 2 (6″ Dia) and Size 3 (3″ Dia) are filled with RTV-3110 silicone rubber. This produces an almost perfect match with TNT. The dielectric constant and (loss tangent) values are 2.89 (0.0023) at 100 MHz, 2.88 (0.0016) at 300 MHz, 2.9 (0.0008) at 600 MHz, 2.93 (0.0047) at 900 MHz, and 2.97 (0.0084) at 1000 MHz (compared to 2.89 (0.0039) for TNT).

The clustered pole locations of the targets measured in a free space environment suggest two possible pole loci in the complex s-plane. Furthermore, both of these pole loci display to some degree a bending of the locus back toward the imaginary axis as poles with higher oscillatory frequencies are considered. This type of pole locus behavior is consistent with the known behavior of the pole loci for dielectric sphere and dielectric-clad metal spheres.

The clustered pole locations as extracted from the free space scattering data are shown in Figures 5, 6 and 7 for respectively the large, medium and small inert targets. The perverse nature of these dielectric targets can be seen from the fact that, in free space at least, suspected natural resonances span the entire measured spectrum for all three targets. Note also that these dielectric targets would not be considered "high Q" in that the damping coefficients are relatively large. A "rough" averaged pole locations for these targets is illustrated in Figure 8. It is somewhat clear even in this Figure 8 that in the 14.5 to 18.0 GHz range the three targets represent a difficult discrimination problem using complex natural resonances unless additional signal processing were used. We believe, however, that even in this frequency span successful identification algorithms could be developed with additional "massaging" of the data.

Clustered pole locations for the large and medium inert targets, on or partially within, a sandy soil medium are shown in Figures 9 and 10 respectively. Rough averages of these pole locations are shown in Figure 11. With the present antenna prototype, data on the small inert target were not available. Note from Figure 11 that the lowest frequencies (< 1.0 GHz) represent the most difficult identification frequency span but even here the problem is not severe.

With the new programs and some operator interactions, a transient waveform could be generated from these natural resonances that "fits" the measured transient signals over some arbitrarily truncated portion of the time axis with essentially zero error is now possible. This confirms the accuracy with which the WCR's have been obtained. Such results, however, are at the expense of additional parameters (poles) in the model. It then becomes necessary to reduce the complexity of the model while retaining a sufficient good "fit" to the measured transient that acceptable identification probabilities are obtained. It is this problem that a next step of the algorithm development procedure would have addressed. This activity is continuing at OSU and is being funded by the university at a very low level.

These same data were also used in the target imaging programs being developed at OSU. A typical image is shown in Figure 12. The data was generated by tilting the mine 15° in elevation as shown in Figure 13. The scattered fields were measured from 2-18 GHz, transformed to the time

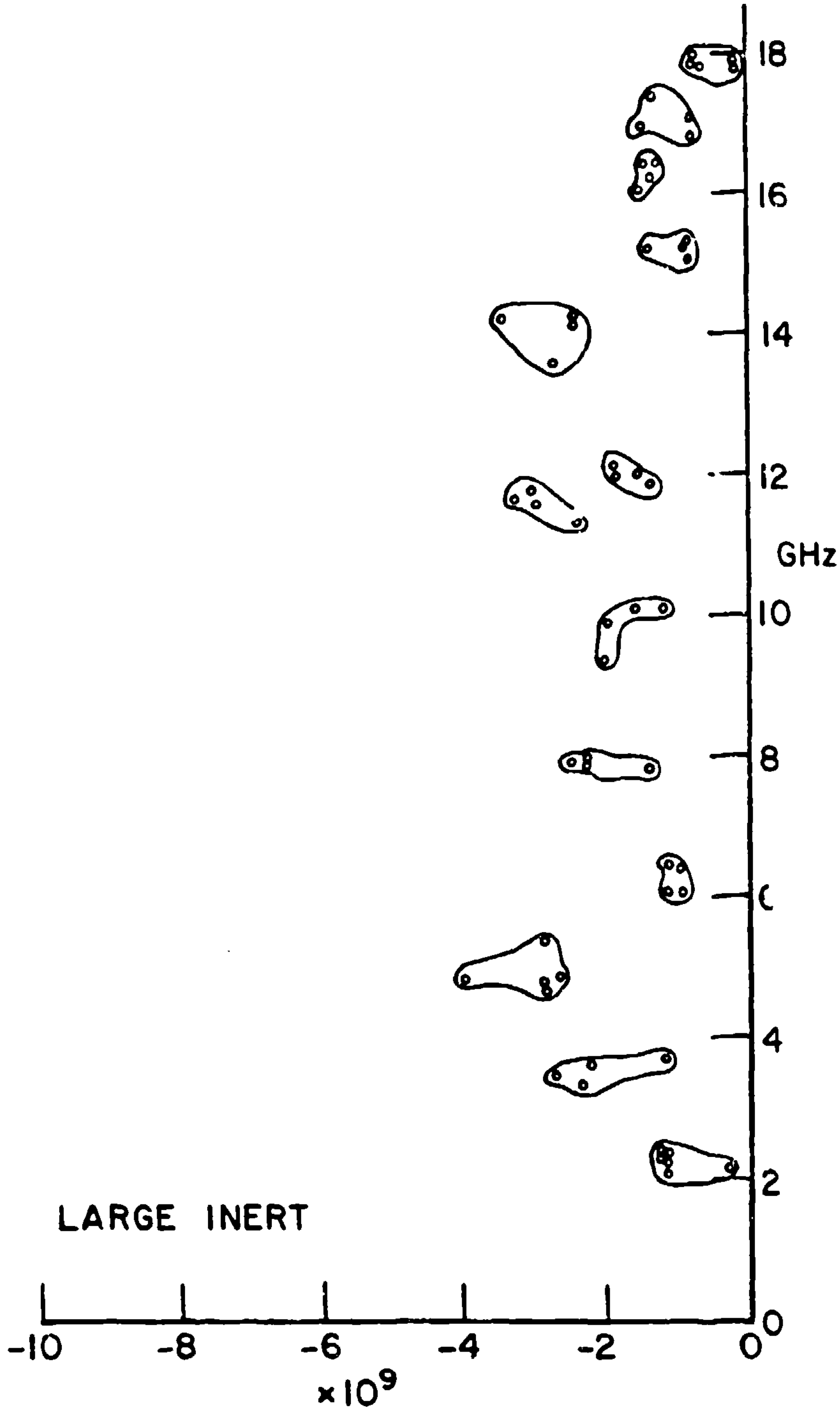


Figure 5: Natural resonances of large simulated mine.

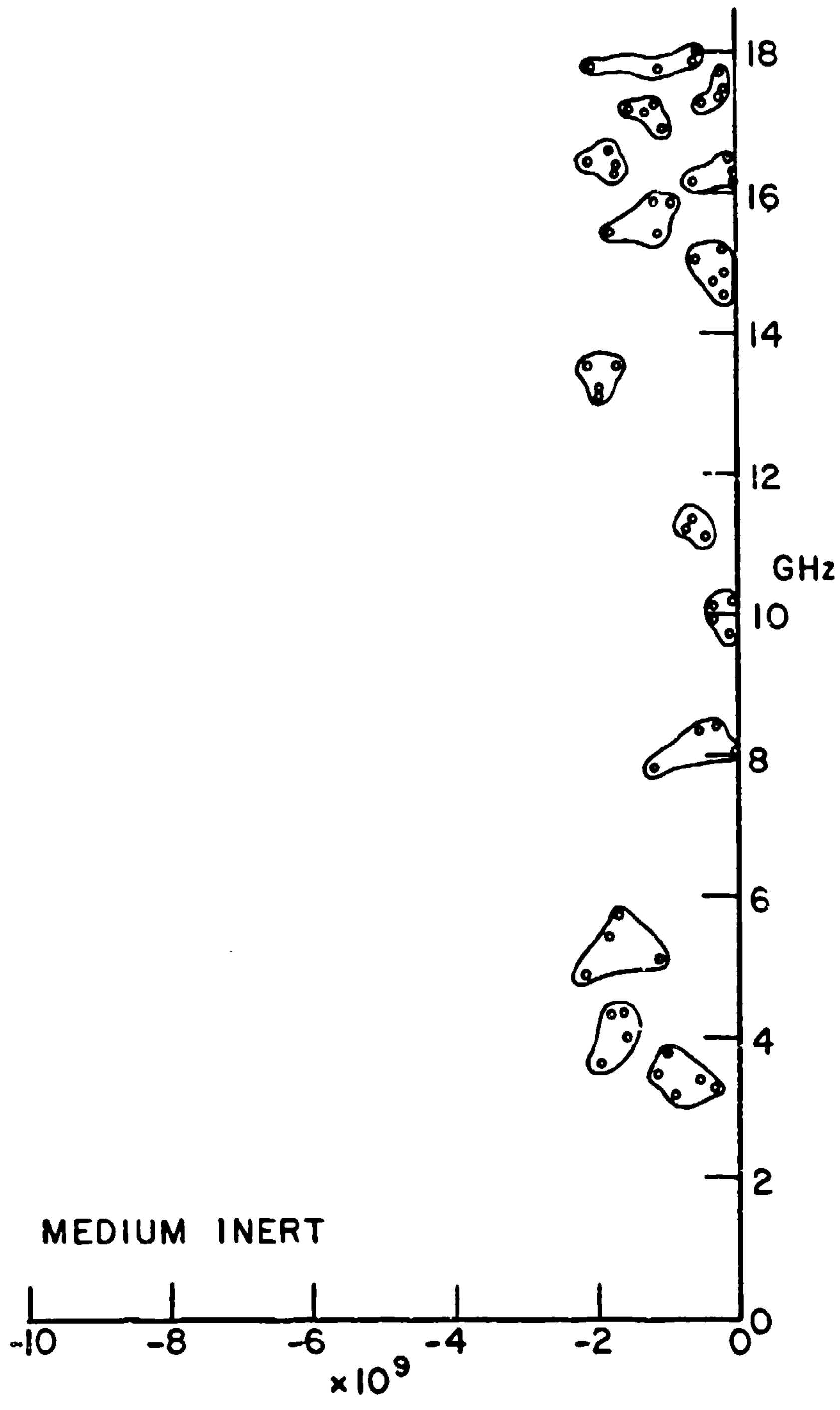


Figure 6: Natural resonances of medium simulated mine.

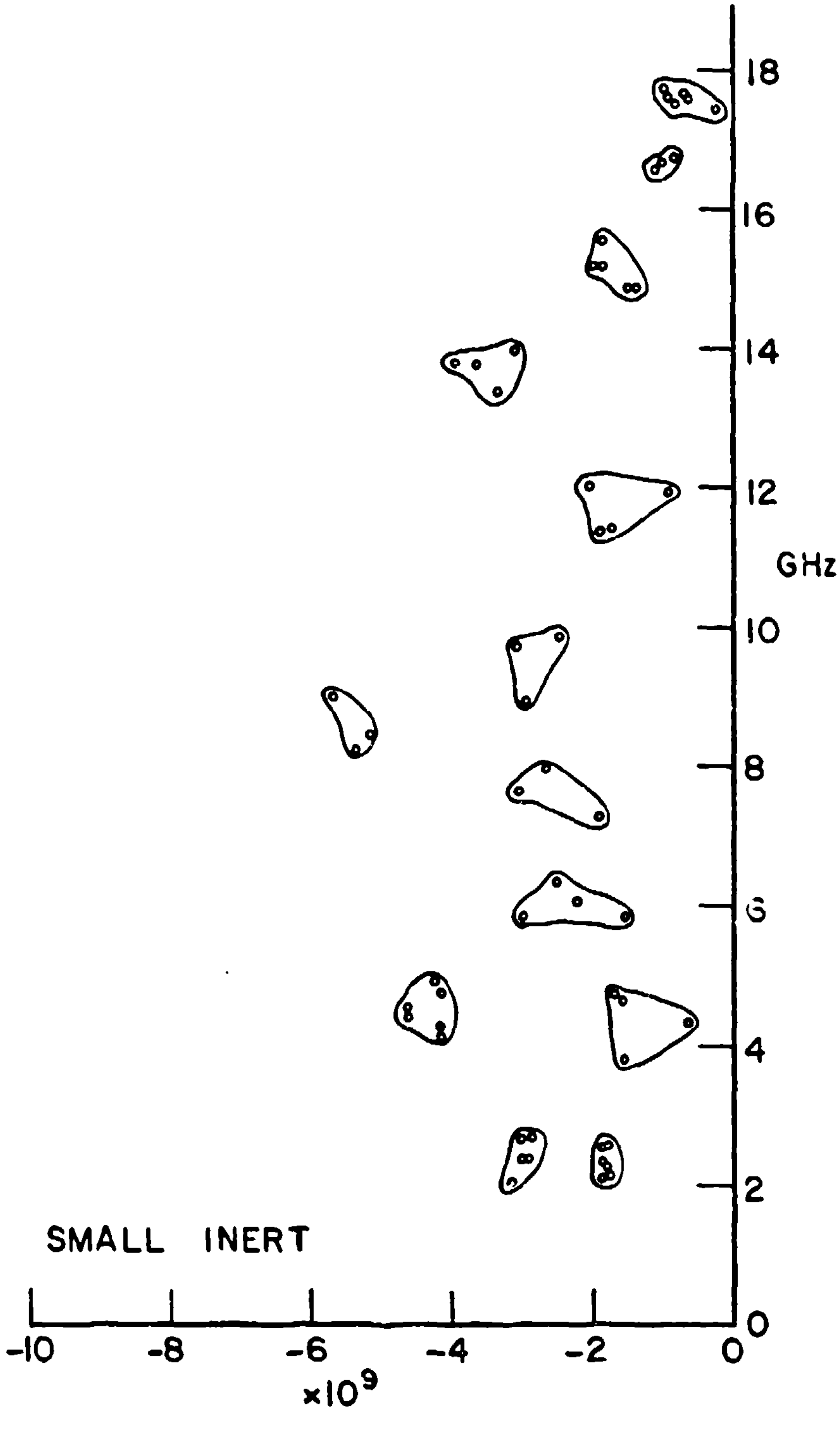


Figure 7: Na'ural resonances of small simula'ed mine.

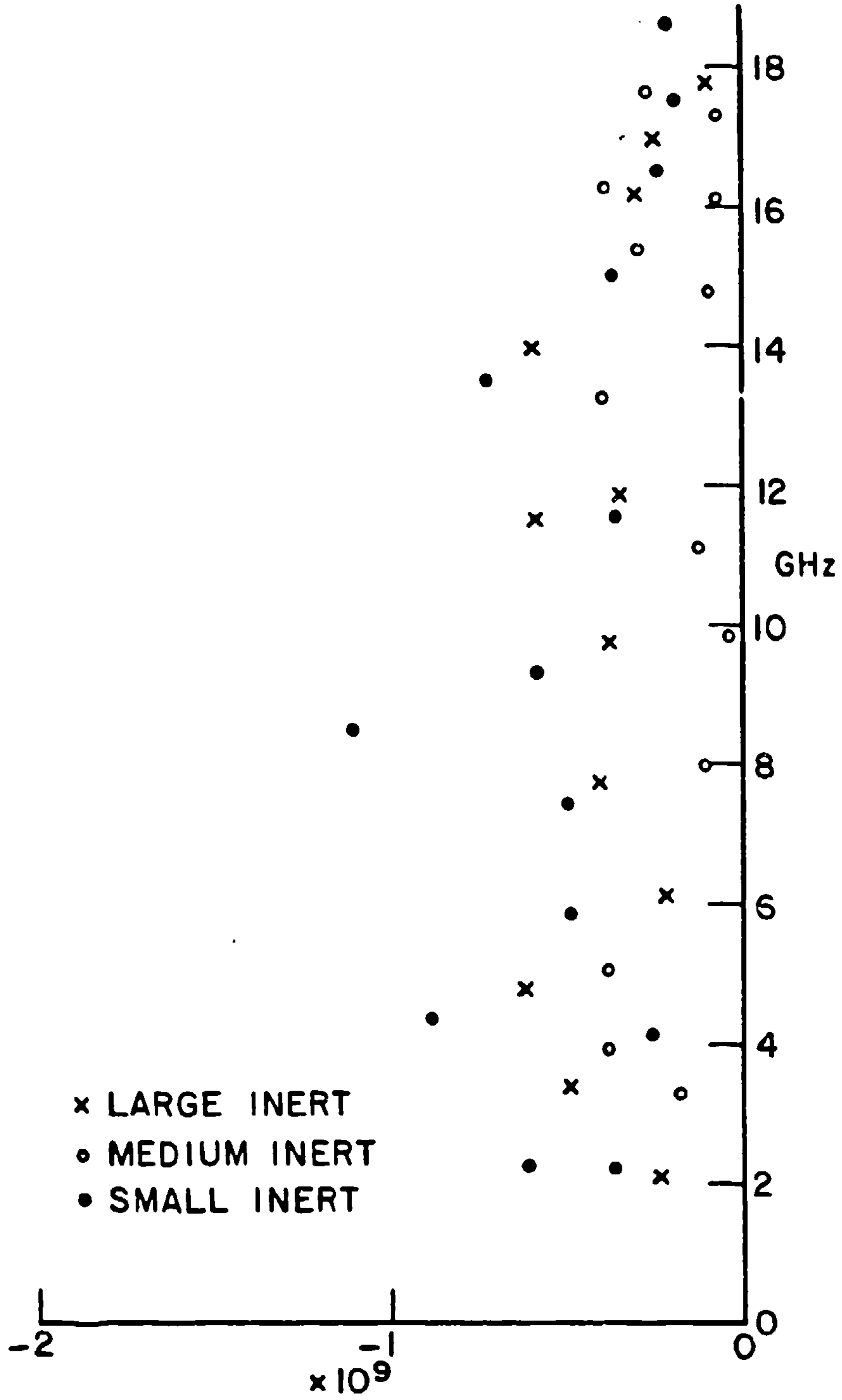


Figure 8: Natural resonances of all simulated mines.

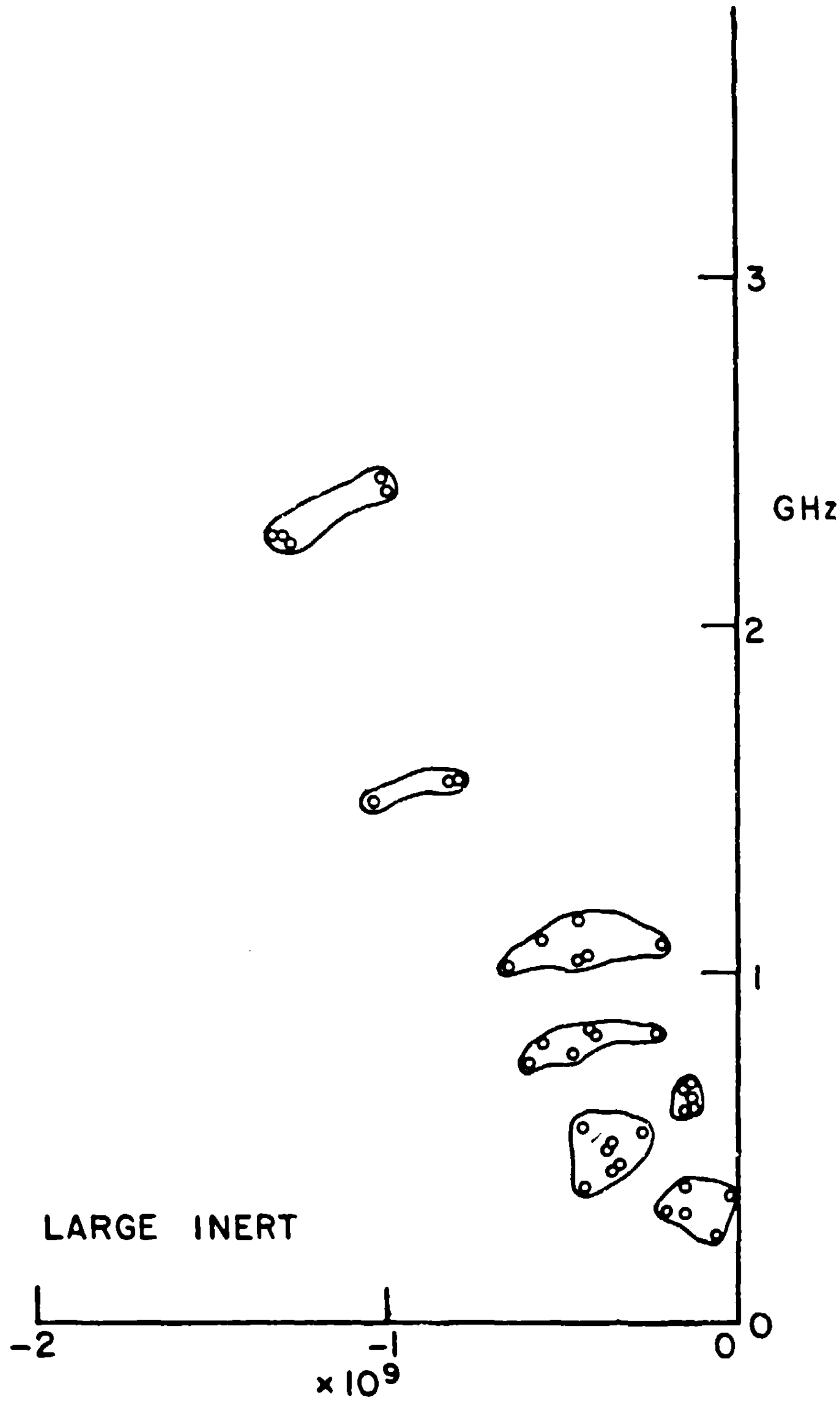


Figure 9:

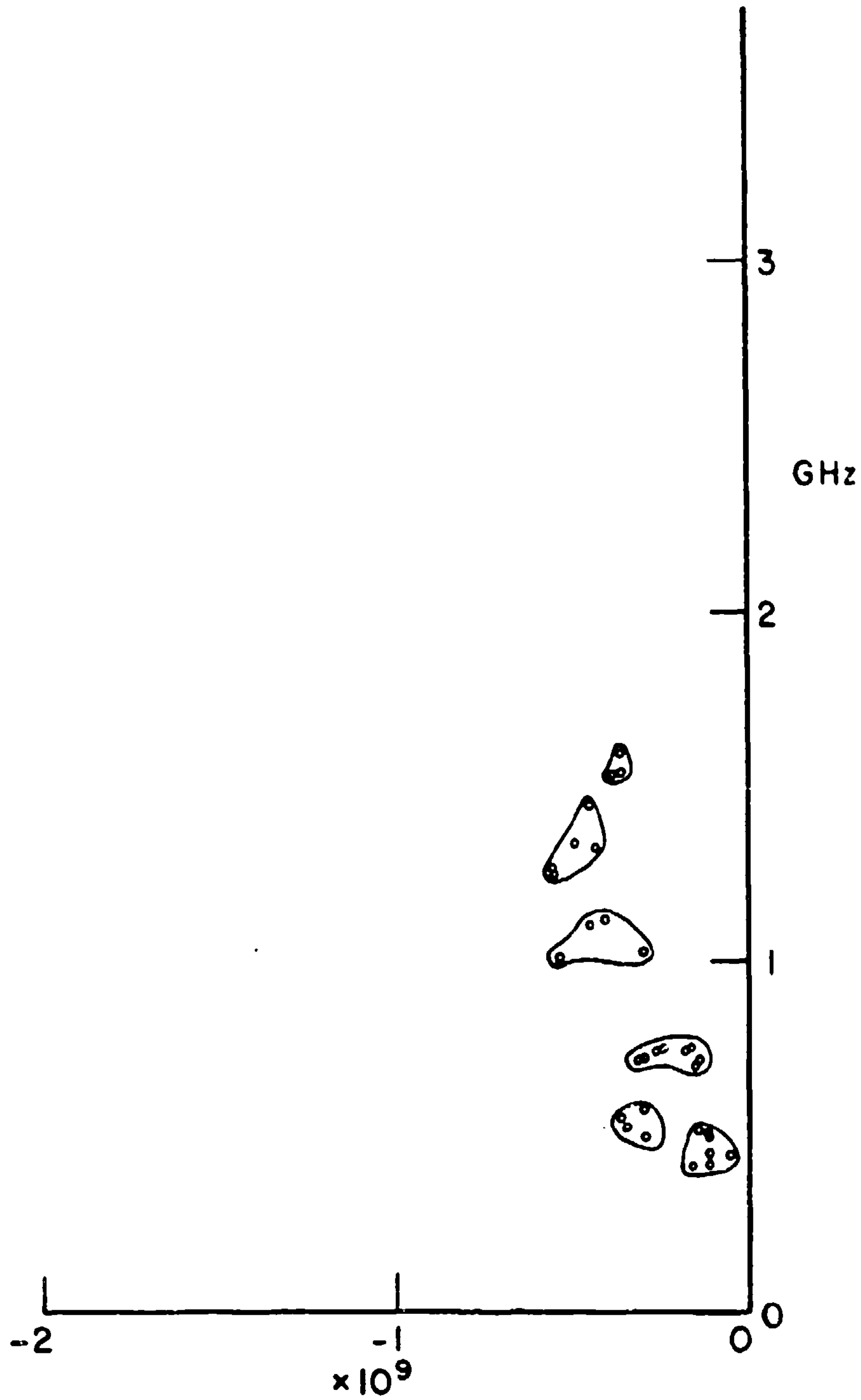


Figure 10:

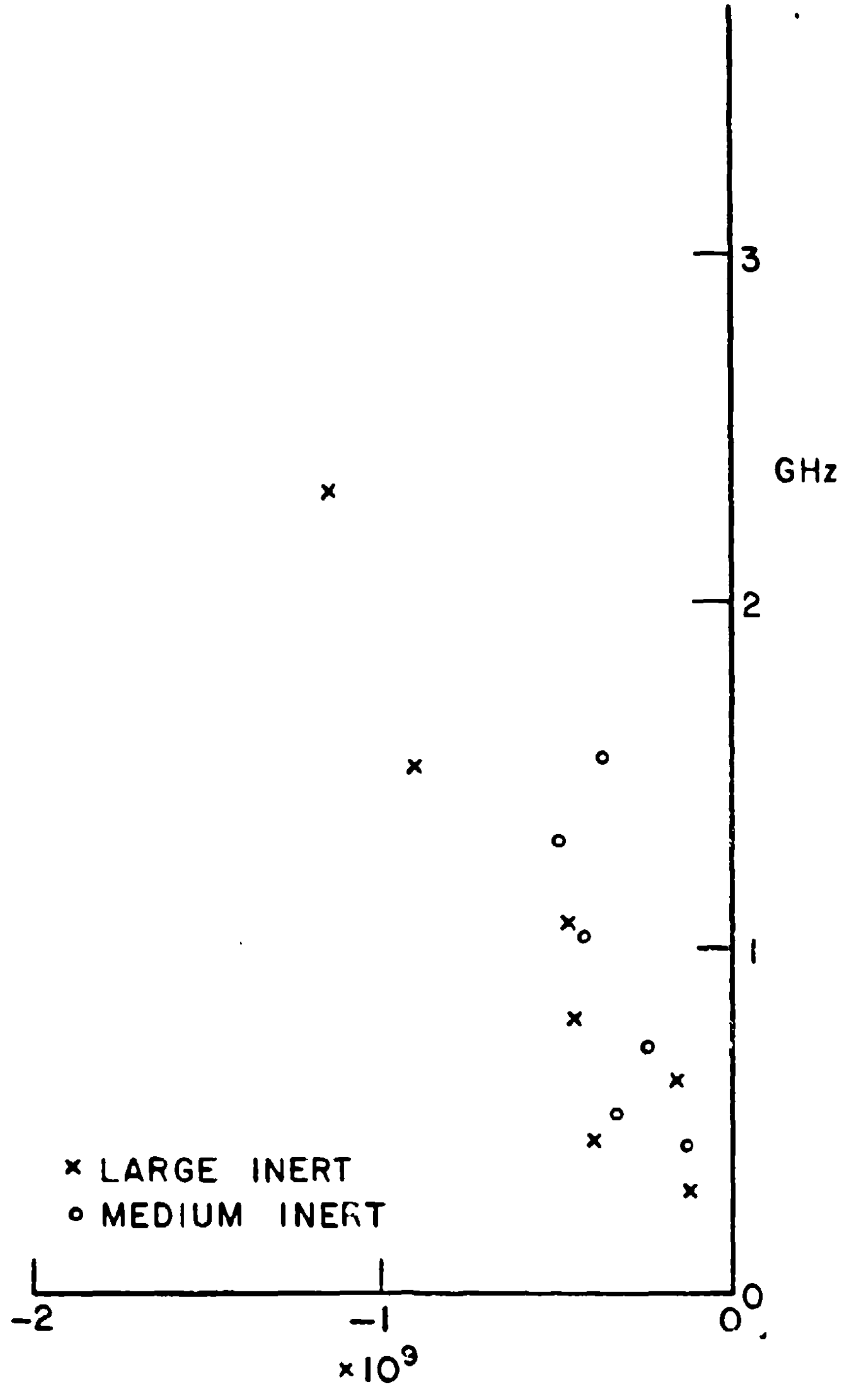


Figure 11:

domain and imaged. The result shows very strong reflections from the shadowed part of the mine showing that strong lateral resonances would be expected.

It is anticipated that this capability will contribute to a better understanding of the physical mechanisms that contribute to any such resonances.

It was originally planned to accumulate comparable data for buried mines using the reflector antenna concept this coming year. These data would then be used to generate natural resonances and compare with those discussed above. Next, the identification algorithms were to be re-examined and updated as required. This represents a full years' effort and would demonstrate the feasibility of the concept.

Some concepts considered at the start of this study have been discarded for practical reasons. One that has fallen by the wayside is the use of the microwave band. The reason is primarily speed since the concept of stepped frequency or chirped radars is too slow if one is to scan a road at a reasonable speed. In contrast, a base band pulse system is such that data can be accumulated in a matter of microseconds. However, these systems are not practical in the frequency range around 10 GHz. Further, the ground can become extremely rough and lossy. Thus, the maximum operating frequency should be on the order of 3 to 5 GHz.

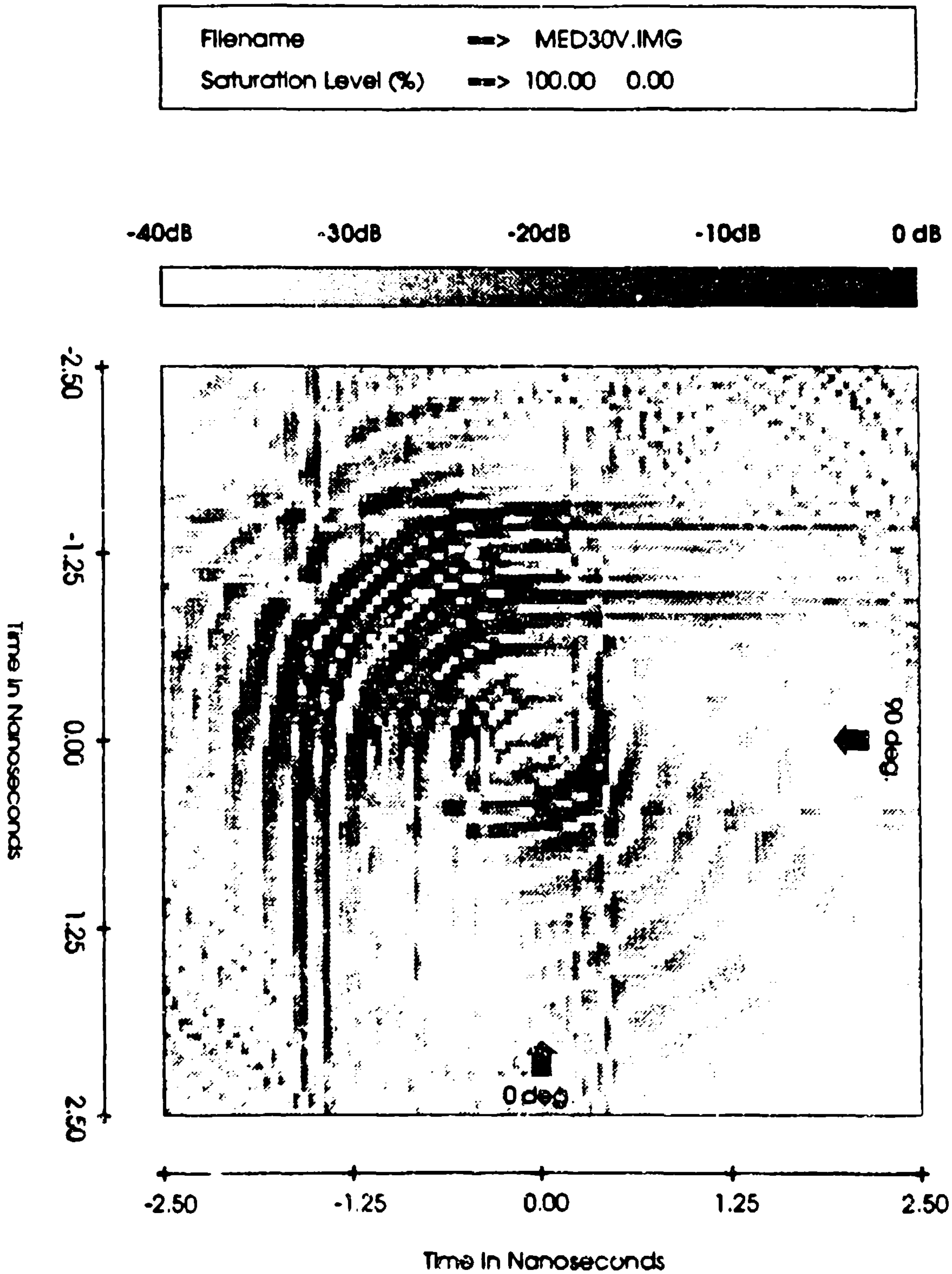


Figure 12: Microwave image of a simulated mine.

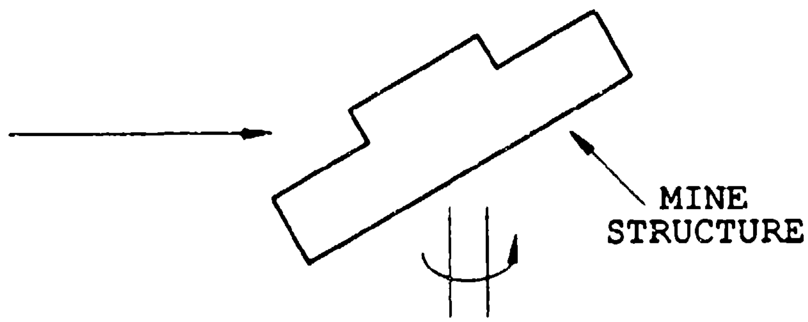


Figure 13: Geometry from which image of Figure 12 was generated. Model was tilted 15° and then rotated about the vertical axis in increments of 10° from 0° to 90°.

V. Array Concepts

The reflector antenna concept may prove to be not practical in terms of scan speed. One possible array technique would consist of using a cylindrical reflector with multiple feed points as illustrated in Figure 14 for two feed positions. The R-card is to be used as will be discussed later to minimize coupling between lines.

An alternate scheme would make use of arrays of elements on an R-card as illustrated in Figure 15. It has been demonstrated by experiment in another program that the appropriate R-card does reduce the coupling but does not significantly modify the broadside radiation.

In each of the array systems there would be a separate pulser unit at each antenna terminal. These would be triggered to position the focussed spot at some chosen spot on the road. Scanning across the road would be achieved by modifying the trigger timing of each pulser. The trigger would be adjusted so that the antenna element would appear to lie on a circle whose center is the desired focussed spot. No two (or more) pulses would arrive at any other spot at the same time. Thus, frequency domain concepts such as grating lobes are not a serious concern. The use of multiple pulsers would also increase the signal to noise ratio.

Further, the receiver could make use of a more modern sampling oscilloscope with multiple channels. This would minimize the time required for scanning a road.

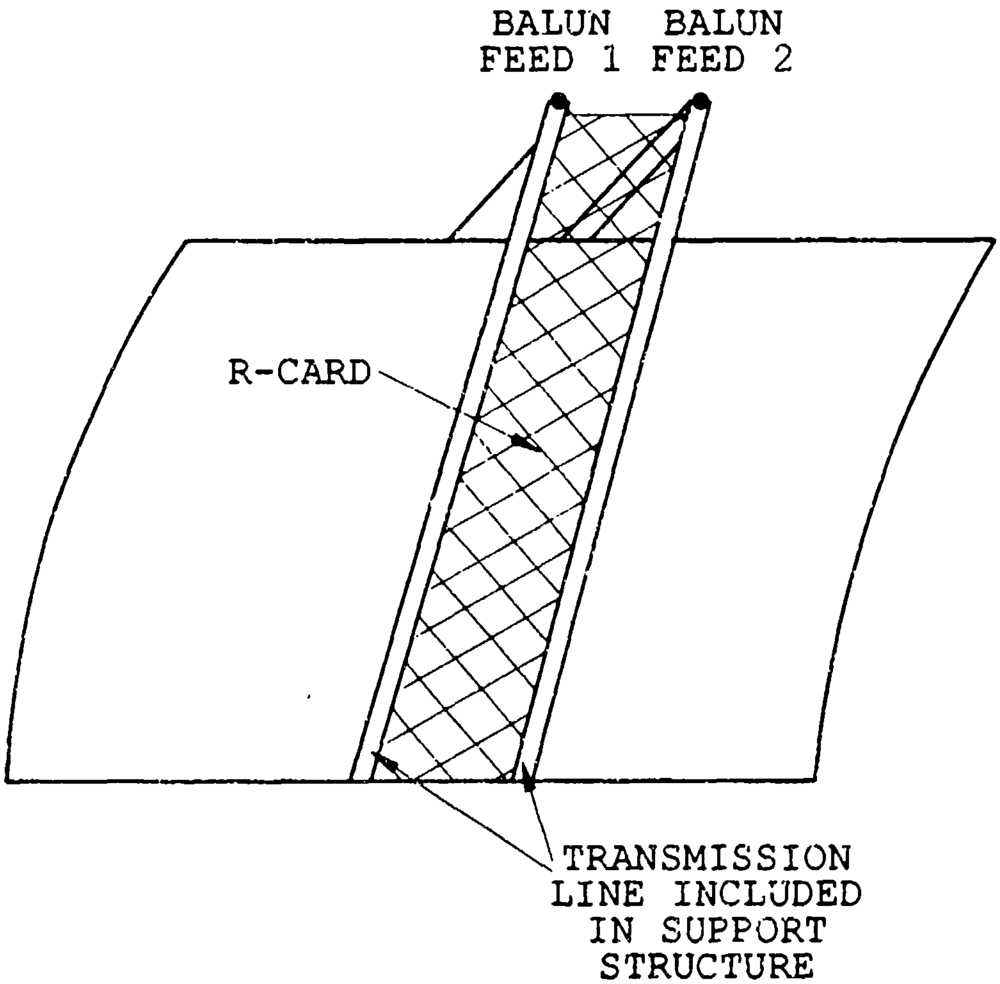


Figure 14: Multiple feed for a cylindrical reflector. R-card is used to minimize coupling.

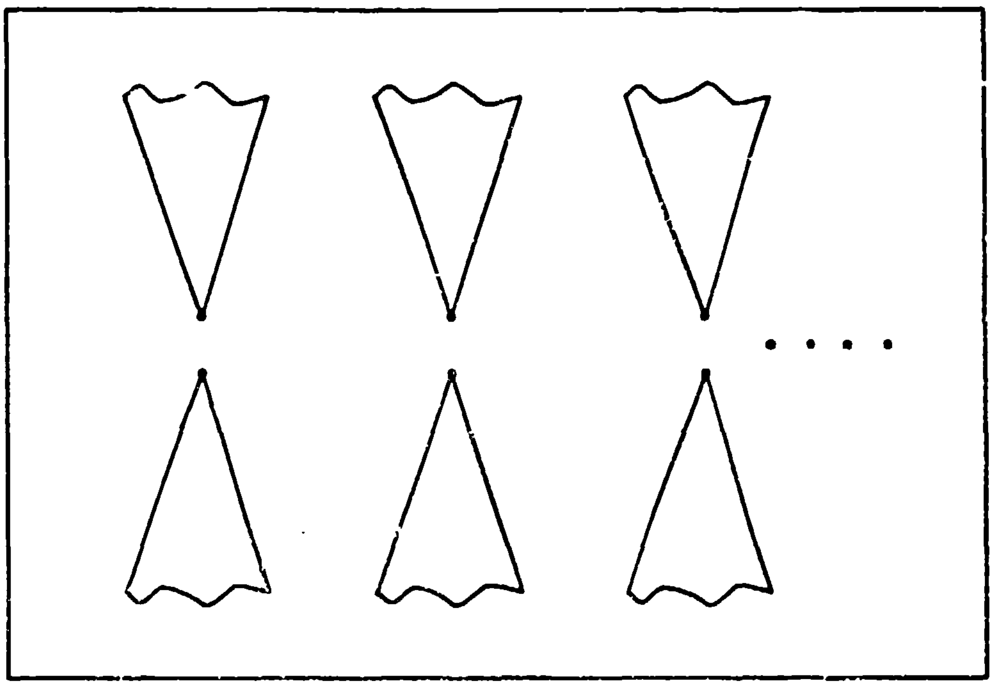


Figure 15: A potential array geometry.

VI. Concluding Remarks

The first steps for the development of a ground penetrating radar for mine detection have proven to be very successful. An antenna that does not need to be located near the ground has been constructed and tested. This is a reflector antenna with a second focii to be located at the ground. A remarkable very broad band feed has also been designed and included. This antenna has exceeded our expectations.

Broad band measurements have been made on simulated mines provided by Fort Belvoir, both in free space and in a buried state. The free space measurements in the frequency domain were made using OSU's remarkable compact range from 2-18 GHz. Measurements in sand and clay were made using a GPR system. These data were used to obtain the target's Complex Natural Resonances (CPR), and the results were quite successful. This was verified by using the CPR data to reconstruct a time domain waveform. This reconstructed time domain waveform provided a good fit with the measured time domain waveform, thus verifying the accuracy of the CPR's. These data would provide the basic data for the prediction-correlator to be used for target identification.

Finally, it is realized that the operation of the above prototype would be far too slow for a practical mine detector. This problem could be solved by introducing a time domain scanning array. The system would use individual pulsers at each element which would be triggered at the appropriate time to focus all elements of the array at a single spot. Using available modem multiple channel sampling scope as a receiver, it should be practical to scan a road at reasonable speeds.

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